AC 29 APPENDIX B. AIRWORTHINESS GUIDANCE FOR ROTORCRAFT INSTRUMENT FLIGHT

a. Explanation. Requirements for instrument flight rules (IFR) have been incorporated into Part 29, Appendix B, utilizing a regulatory format. Various information from previous interim standards, procedures, test techniques, and acceptable means of compliance for rotorcraft IFR flight are included in the following sections.

b. Procedures.

(1) General.

(i) The certified instrument flight envelope may be more restrictive than the visual flight rules (VFR) envelope in terms of weight, center of gravity, speed, altitude, or rate of climb and descent. The approved envelope should be operationally practical such that it does not impose constraints with which the crew has difficulty complying.

(ii) Controllability requirements are to be met from 0.9 V_{MINI} to 1.1 V_{NE}. Stability requirements must be met where specified. Stability devices are to be designed to allow safe flight following a failure. The evaluating pilot should assure that all equipment and devices installed for IFR, including reasonable failures of that equipment, do not compromise the VFR approval for that rotorcraft. An example of this would be a stability system failure that caused loss of swashplate or tail rotor control travel when failed in a hardover condition. If the device remains in the hardover position after the stability system is turned off, control capability may be compromised. Cyclic controllability tests at high speed and at the limiting rearward flight condition, or tail rotor tests in sideward flight at high altitude, may reveal a lower control capability and a more restrictive envelope. In addition, controllability testing should be accomplished with the control rigging set at the most adverse production tolerance for the test condition; e.g., minimum forward swashplate for high speed testing.

(2) Trim. Compliance with the IFR trim requirement may be met by use of a magnetic brake with a recentering button, an electrically driven trim system activated by a “beeper” type control, or other means, so long as the system does not introduce any objectionable discontinuities in the force gradient or otherwise result in objectionable flight characteristics. Trim release devices should be free of objectionable stick jump. Electrically driven trim systems should have a smooth change in force with a rate compatible with the normal rotorcraft maneuvers. Only the cyclic trim control must exhibit positive self-centering characteristics. Collective and directional controls are not required to incorporate positive self-centering characteristics, but these controls should not move when released by the pilot (adjustable friction devices are satisfactory); however, for systems which use hydraulic or pneumatic dampers, control motion following release by the pilot is permitted during the time interval when the damper is bleeding off. Movement of the trim controls should produce a similar effect on the

rotorcraft in a plane parallel to that of the control motion. The control system free play and breakout force must be evaluated to assure a close and direct correlation between control input (force and deflection) and rotorcraft response (pitch, roll, yaw, and heave (vertical motion)), and to permit small, precise changes in flight path. If trim control is provided in a stability augmentation system (SAS), the control should be of such design and so installed that any failure will not create a hazardous condition. If an inadvertent out-of-trim condition can be developed, its effect on the rotorcraft should be investigated. These failures or malfunctions should be investigated as outlined in (6) "Stability Augmentation Systems" which follows. The controls for this trim function should be installed such that, the controls should operate in the plane and with the sense of motion of the rotorcraft. Each control means should have the direction of motion plainly marked thereon or adjacent to the control.

(3) <u>Static Longitudinal Stability</u>.

(i) Positive static longitudinal stability is a key IFR requirement which assures a self-correcting airspeed response and allows a pilot to recognize any substantial change in speed. The phrase "substantial speed change" as used in FAR 29, Appendix B, Paragraph IV, is normally considered to mean at least a 10 knot departure from trim speed. Such a change in airspeed must be accompanied by a stick force clearly perceptible to the pilot (i.e., a discernible and quantifiable force gradient). Very shallow force gradients can be approved for systems with low deadband and low friction. Systems with significant friction and deadband require much steeper force gradients to be acceptable. The longitudinal force gradient can be determined by either of two methods. The most commonly used method (applicable only to irreversible control systems) measures the cyclic forces with the rotorcraft on the ground and the rotor stopped (with hydraulic and electric power units if required). The force applied to the cyclic stick and the cyclic stick displacement are measured and a plot of stick force versus displacement in each longitudinal direction is obtained. Following the ground test, the longitudinal static stability tests are conducted in flight as described in paragraph AC 29.175. The cyclic displacement measurements gathered during flight test are then assigned force values from the ground mechanical characteristics test and the force values are cross plotted with the corresponding airspeeds to produce a plot of cyclic force versus airspeed. The trim system should be on during the test and the aircraft trimmed at the trim speed. After each end point, the cyclic should be allowed to slowly return to the trim position. When all the force is released from the cyclic stick and the airspeed has stabilized, note the airspeed. An alternate method of determining the longitudinal stick force stability is to measure the force on the cyclic stick in flight using a hand held force gage or other force measuring instrumentation. The in-flight technique is the same as the first method. Testing should be accomplished at a minimum of two altitudes. One altitude should be low enough to assure limiting power is attained. Another should be at or near the maximum approved altitude. Reasonable interpolation is allowed. If no marginal areas are apparent interpolation over a 10,000-foot altitude range is considered reasonable.

(ii) Tests for static longitudinal stability during approach should include the steepest approach gradient for which approval is requested. Static stability tests may be simulated by initially establishing a trimmed rate of descent for maximum approach gradient assuming zero wind conditions. Actual approach tests at the maximum approved gradient should be conducted to evaluate tracking and maneuverability, including the capability to correct downward to a glide path when approaching in a slight (10 knot) tailwind condition.

(4) <u>Static Lateral - Directional Stability</u>.

(i) Tests for directional stability usually require instrumentation for lateral cyclic position, pedal position, and sideslip angle. Testing for compliance with the specific directional requirement is relatively simple; however, the pilot should look for significant longitudinal trim changes and short period dynamic modes which might occur only during sideslip conditions. Side force characteristics are indicated by the variation of bank angle with sideslip during steady heading sideslips. The number of ball widths of deflection is also indicative of the side force cue available to the pilot. A correlation between sideslip angle and ball widths of skid can be obtained at given speeds for use during later testing after sideslip instrumentation is removed. A simple yaw string can be calibrated in a similar manner. The TIA should define the maximum sideslip angles which should not be exceeded during the flight test program. These angles must not be greater than the structural sideslip envelope substantiated and are not required to be that sideslip angle obtained with full directional pedal deflection. Sufficient side force cues should accompany sideslip to alert the crew when approaching sideslip limits. This is needed to assure that structural sideslip limits will not be inadvertently exceeded in service. Although not stated in the requirement, flight conditions for demonstration of static longitudinal stability are also appropriate for demonstration of static lateral-directional stability.

(ii) Dihedral requirements may be more difficult to assess. For those rotorcraft which do not meet the position and force gradient requirements for the conventional, cross-controlled sideslips, there are alternative tests which may be used to determine acceptable characteristics. If directional pedals are utilized in steady sideslips, the resultant rolling tendency is the sum of (1) the aircraft's roll due to sideslip tendency (dihedral) and (2) the aircraft's roll due to directional control input. If the rotorcraft has a tail rotor which is excessively high or low in relation to the rotorcraft's vertical center of gravity (CG), application of tail rotor thrust will introduce a significant rolling moment. The basic intent of dihedral stability testing is to determine the rotorcraft response to sideslip exclusive of directional control input. In general, if a tail rotor configuration is involved, and the tail rotor is above the vertical CG of the rotorcraft, the effect of pedal input upon dihedral effect is destabilizing during conventional, control-induced sideslips.

(iii) There are two alternate methods which, for small angles of sideslip, can give an indication of the basic dihedral stability of the rotorcraft. Both methods involve freezing directional controls while artificially creating sideslip by other means.

(iv) The first method is only applicable for rotorcraft with single main rotor systems. To utilize this method, the rotorcraft is stabilized in a given flight condition and small collective (torque) changes are applied in each direction (e.g., ±5% & ±10%) while holding pedals fixed. Sideslip angle, lateral control position, and lateral control force may be measured and plotted for small torque changes from trim. This technique will not work for aircraft which have collective to pedal or collective to lateral control couplings.

(v) In the second method, the rotorcraft is stabilized in a trimmed flight condition with a small amount of bank (5-10°). The rotorcraft is then rolled to an approximately equal angle of bank in the opposite direction holding the pedals fixed. The change in direction of bank results in a small change in sideslip angle and again sideslip angle may be plotted versus lateral control position and/or force. This test should be conducted in both directions and the results averaged. This method can give reasonably accurate results for small perturbations. Other factors contribute to the results of either of these two methods. It is always important to assess the roll due to sideslip tendency with pedal induced sideslips to assure lateral control forces are reasonable and in a proper direction for directional out-of-trim conditions, and to assure the pilot has adequate sideslip cues.

(vi) Wording of the dihedral requirement is intended to allow slightly negative dihedral stability at critical loading conditions. This will ordinarily result in positive dihedral stability throughout a great majority of the approved loading envelope. The test for maximum allowable negative dihedral effect would involve stabilization at a required flight condition, inducing a sideslip up to ±10° from trim, then assessing lateral cyclic friction/deadband to determine if roll is restrained while remaining in the control system friction/deadband so that the control may be released without resulting in the aircraft rolling in the adverse direction. When testing for this condition, lateral cyclic friction should be adjusted to the minimum value.

(vii) The intent of the dihedral rule is to allow small amounts of control system friction and deadband to mask small values of negative dihedral. Where slope of the negative dihedral versus sideslip exceeds these small values, the negative dihedral shall not be approved. The operational pilot must not be presented with opposite cyclic sensing for similar sideslip conditions as loadings and flight conditions change. In general, large values of control system friction and deadband are undesirable. The addition of friction or deadband into the control system for the purpose of satisfying the dihedral requirement is not acceptable.

(viii) In approving small negative dihedral values, the pilot should ensure that other positive flight cues, such as suitable side force, accompany sideslip. This will aid the pilot in determining direction of sideslip so that no reverse sensing or confusion accompanies sideslip conditions.

(5) <u>Dynamic Stability</u>.

(i) Dynamic characteristics are defined in quantitative terms; however, some areas of interpretation and technique need special consideration:

(A) Unlike fixed-wing aircraft where the size of the input has no effect on damping ratio, rotorcraft can be sensitive to the type and size of input used to excite each dynamic mode. For instance, it has been found that for the phugoid-type dynamic oscillation, damping ratio is inversely proportional to the size of the input. It therefore becomes important that dynamic excitations be sized to approximate the response of the rotorcraft in a moderate turbulent gust. Also, the dynamic input should be made with the control(s) which most accurately simulates the typical aircraft gust response. Obviously, for this evaluation some flying of the rotorcraft in turbulence is necessary to obtain knowledge of the rotorcraft's gust response. Pulses and doublets may be used to generate disturbances similar to a gust. To assist returning the control(s) to the trim position a hand held jig may be used. Use of attitude and rate instrumentation is desirable. The pilot may find that collective excitation, or collective in conjunction with cyclic, is most appropriate for gust simulation.

(B) The second area of concern in evaluating dynamic response is whether to let only one axis respond to an excitation or to let the rotorcraft respond in two or more axes. When it can be done safely, the rotorcraft should be allowed to follow its dynamic response in all axes. In other words, if pitch oscillations feed into roll, the pilot should attempt to observe and record the total aircraft dynamic response in both pitch and roll.

(C) The third area concerns strict compliance with the exact wording of the dynamic requirement. In this regard, a neutrally damped oscillation with a period of 19 seconds would not be acceptable; however, a very divergent oscillation that doubles in amplitude in 21 seconds would be acceptable. The 19-second oscillation is much less severe than the 21-second oscillation and yet is unacceptable by the "letter of the law." Figure AC 29 APX B-1 below is a graphical display of the dynamic requirement. The 19- and 21-second oscillations are shown as points (1) and (2). Point No. 1 is positioned much more toward the acceptable portion of the graph and yet by the "letter of the law" is unacceptable. The intent of the dynamic requirement is roughly approximated by the dashed-curved line. Areas to the right of that line may be considered for findings of equivalent safety.

(D) A fourth area requiring special care in testing is the aperiodic requirement. The most common aperiodic motion is the spiral characteristic which results when aircraft attitude is displaced in roll. The preferred method for testing this requirement is to stabilize precisely on a trimmed condition in straight flight, then displace the rotorcraft to 10° of bank, stabilize momentarily, set the controls as they were positioned for straight flight, and release them. Time and bank angles are then recorded. Recovery is initiated when bank angle or roll rate becomes excessive. Of particular interest is the time for bank angle to pass 20° and this time should not be so short as to cause the aircraft to have objectionable flight characteristics in the IFR environment. The time period to double amplitude (20°) should be at least 9 seconds. It is vitally important that controls (particularly lateral cyclic) is positioned exactly as it was for the straight flight condition. If a high resolution force trim system is not incorporated, an alternative method may be used. In this second method, the rotorcraft is trimmed for straight flight as described above and controls are released. Roll attitude may simply be allowed to vary naturally with time or small pulse input may be made with pedals. It is important that controls are positioned precisely as they were for the trimmed, straight flight condition and a plot of bank angle versus time is obtained. This plot is then compared against a divergent roll condition which doubles in amplitude every 9 seconds. Of particular interest is again the rate passing 20° of bank. If airspeed changes as the aircraft rolls or if roll/pitch coupling occurs, these changes should be allowed to interact naturally until recovery is necessary. Due to the sensitive nature of this test, smooth air is essential. Repeatability may be a problem. At least two test points in each direction should be obtained at each trim condition. Results may be averaged if they show reasonable repeatability. The same procedures may be utilized for an aperiodic pitch response; however, a displacement of 5° from trim should be used and of particular importance is the pitch rate passing 10°. Again, at least two test points in each direction should be obtained for each trim condition. Although not stated in the requirement, the flight conditions for demonstration of static longitudinal stability are also appropriate for demonstration of dynamic stability. The degree of testing referred to here represents that which might be required of a marginally stable rotorcraft. For those configurations which provide good aerodynamic stability or use varying degrees of SAS, the scope of the demonstration program would be decreased significantly.

(ii) Control system dynamics should also be evaluated. This may be accomplished by lightly bumping each control in flight and observing its free response. Any resulting control motion must dampen quickly and should not be driven by aircraft/control system interaction. This will assure safe flight in the event a control is inadvertently bumped or released from an out-of-trim condition.

(6) <u>Stability Augmentation System (SAS).</u>

(i) If a SAS installation stabilizes the rotorcraft by allowing the pilot to “fly through” and perceive a stable, well-behaved vehicle, it qualifies as a SAS, and if reliable, receives credit under Sections III through VII of Appendix B for use in complying with all-handling qualities requirements. If a conventional autopilot does not provide “fly through” capability or allow the pilot to perceive a stable, well behaved vehicle through his manipulation of primary flight controls and feedback from those controls, then it tends to remove him from active involvement in flying and is eligible primarily as a workload reliever.

(ii) If handling qualities credit is given for a SAS then it must be shown to be reliable. If a reliable SAS is incorporated, it should be operational during handling qualities testing for trim and stability. Reasonable single failures of the SAS must be evaluated and the resultant handling qualities must be evaluated to assure that in this degraded configuration, (1) handling qualities have not been degraded below “VFR” levels defined in FAR Part 29, Subpart B, (2) the rotorcraft is free from any tendency to diverge rapidly from stabilized flight conditions, and (3) the rotorcraft can be flown IFR throughout its endurance capability without undue difficulty by the minimum flight crew. Compliance with a majority of the IFR handling qualities requirements is desired and the degraded characteristics should be documented and explained. Revised flight envelope boundaries for the failed condition may be considered if they are controllable by the pilot, e.g., altitude and airspeed. When loss of a SAS results in a need for minor adjustment of a flight condition then a system can be accepted that allows failures during the life of each rotorcraft. If loss of the system will prevent continuation of safe flight and landing, the reliability of the system must be high enough to assure that failure of the system will not be expected to occur during the life of the rotorcraft fleet. When evaluating the reliability of a system, the installation of the system should be considered as part of the design. The total system including inputs, outputs, environment, isolation features, and exposure times is a pertinent consideration.

(iii) Stability augmentation system reliability is evaluated by Systems and Equipment personnel. If credit is to be given for system reliability and the applicant exempted from consideration of malfunction, hardover and oscillatory conditions (limited to critical frequencies determined during autopilot failure analysis), a thorough system evaluation is needed. Flight test personnel should coordinate closely with the systems and equipment personnel whenever credit is given for advanced design and system reliability because the hardover/malfunction condition may not require in-flight testing. The decision is made on the basis of system design, failure analysis, and overall probability of malfunction. If flight testing is required, appropriate delay times as shown below, are required. If the system is to be approved without flight restrictions (operating at all times), malfunctions should be demonstrated to be satisfactory during takeoff, climb, cruising, landing, maneuvering, and hovering. If a flight restriction is provided, it should be determined to be an appropriate and relevant operating limitation, and it should be specified in the rotorcraft flight manual. Significant information regarding the restriction should be made available to the pilot in the operating procedures section of the rotorcraft flight manual. If the restriction excludes operation under any of the flight conditions listed above, flight testing of the condition is not required.

Flight Condition	Time Delay
Hover, takeoff, and landing	Normal pilot recognition and reaction time
Maneuvering and approach	Normal pilot recognition plus 1 second Note: Recovery from simulated malfunctions of any SAS axis occurring while the pilot is applying control inputs to cause rotation about that axis may be initiated with normal pilot reaction; the 1-second delay in maneuvering flight pertains to established turns (level, climbing, and descending) only.
Climb, cruise, and descent	Normal pilot recognition plus 3 seconds

For rotorcraft requiring a minimum crew of two pilots and with stability systems that do not have coupling capability such as vertical speed hold, altitude hold, or navigation tracking, a time delay of 1 second may be used in climb, cruise, and descent. Reference to visual cues is assumed only in hover, takeoff, and landing. For other flight conditions, the pilot is assumed to recognize the malfunction condition without reference to outside visual cues. If the stability system has not previously been certified as a part of the aircraft for VFR flight, malfunctions should also be conducted throughout the VFR envelope utilizing the appropriate delay times in Advisory Circular 29-1. Pickup to a hover, landing, sideward, rearward, and forward hovering flight must be considered, because of the visual cues available to the pilot operating VFR, shorter delay times following stability system malfunctions may be appropriate. These delay times are:

(A) One to 3 seconds delay for cruising flight. (The time delay selected should be based upon the degree of stability provided and the amount of alertness required of the pilot. For example, a 3-second delay would normally be appropriate for cruise speeds up to and including V_H while a 1-second delay would be appropriate from V_H to V_{NE}.

NOTE: If the improved stability and the resultant higher degree of relaxation by the pilot has justified time delays greater than 1-second minimum in cruise, then a reexamination is in order of the engine failure time delays used during the original type certification prior to the SAS installation.

(B) One second delay for climbing flight.

(C) Zero second delay for takeoff, landing, hovering, and maneuvering flight.

(iv) A good method to accurately determine pilot recognition and reaction time is to establish typical climb, cruise, descent, and approach conditions and instruct a subject pilot to react as soon as he recognizes individual hardover conditions in pitch, roll, yaw, and heave (if installed). Several pilot subjects may be used. Sensitive recording instrumentation is needed to show the hardover input to the actuator and the pilot's initial control movement. This procedure is usually conducted prior to the critical hardover tests so that the total necessary time delay (recognition plus 3 seconds, etc.) can be established. This procedure actually determines recognition plus reaction time, although reaction time has been shown in hardover testing to be a relatively constant 0.5 seconds. Different recognition times for various axes are not unusual. During one recent program, recognition time for directional hardovers was 0.3 second, but for roll hardovers was 0.9 second. There is typically 0.1 second or less scatter among properly briefed pilots. Recognition time is then added to delay time to determine total necessary delay for hardover testing. As an example, for the above roll condition, a single pilot configuration would require a total 3.9 second duration from signal input to initial control actuation for recovery. Allowable attitude excursions must also be considered. Although allowable attitude excursions during hardover testing probably depend more upon acceleration and rate of acceleration than on attitude, a general rule of 30° pitch and 60° bank may be used. For some designs, maximum safe attitudes may be lower. Certain responses with rapid initial motion, but self-correcting characteristics thereafter have been allowed to diverge as much as 55° in pitch and 80° in roll as long as no rotor system or control difficulties result during malfunction or recovery. The key is: Can a safe, reasonable recovery be made without exceeding aircraft limits? During high speed malfunction testing, the maximum speed allowable during malfunction or during recovery is 1.11 V_{NE} (V_{DF}). The maximum allowable speed for SAS operation must be adjusted to prevent exceeding V_{DF} during malfunction testing at any altitude.

(v) Applicable procedures and techniques for conduct of hardover tests are contained in paragraph AC 29.1329. All cockpit emergency controls including emergency quick disconnects should be "red." The quick disconnect may be actuated at initiation of recovery. Other disconnects should only be actuated after full aircraft control has been achieved following recovery. Aircraft limits may not be exceeded during malfunction or recovery. If a monitor device automatically disconnects the SAS, it must be clearly annunciated to the crew.

(vi) Series actuator hardover conditions in some rotorcraft can seriously degrade control margin. Critical loadings, power settings, RPM, and altitudes in conjunction with a SAS actuator hardover in an adverse direction can result in reduction of control travel requiring flight envelope constraints. Flight testing is usually necessary to determine the appropriate flight envelope reductions.

(vii) Subsequent failures and unrelated probable combinations of failures must be considered, including subsequent SAS failures. Systems and equipment section analysis should provide necessary SAS malfunction combinations for flight testing as a result of their system analysis. Minimum requirements for dispatch and procedures following failure should be included in the malfunction analysis. Results of the probability analysis and the resultant malfunction configurations are primarily the responsibility of the systems and equipment section.

(viii) No reasonably probable failure should result in a worse condition than that tested for hardovers. For example, if a magnetic brake force trim system is employed, failure of electrical power to the magnetic brake circuit may cause the cyclic control to fall which may result in a more dangerous flight condition than individual SAS hardovers. The overall control system is to be evaluated for all probable failures to preclude hazardous failure conditions. Other areas for investigation include beep trim and auto trim failures. The delay times of paragraph b(6)(iii) are appropriate for all such failures. System malfunctions may also include component failures which result in oscillatory outputs of the actuator(s). These should be sustainable at least as long as the specified hardover delays, should be manageable thereafter with hands on the controls, and should allow disconnect of the malfunctioning system.

(ix) Engine failure requirements are not entirely consistent with the SAS failure time delays shown in paragraph b(6)(iii). Engine failure time delays remain as specified in § 29.143(d) and they are lower than corresponding SAS failure delays. Critical engine failure conditions should be reverified during simulated instrument flight with primary reference to flight instruments. Lower time delays for engine failure have been justified on the basis of immediate cues for the critical high powered condition, and requirements for engine failure warning systems. Many rotorcraft designs simply cannot endure a 3-second time delay for critical engine failure conditions. Nevertheless, engine failure, autorotation entries, and autorotation descent (for single engine rotorcraft and multiengine rotorcraft without Category A engine isolation) must be evaluated in simulated IFR conditions and these flight characteristics must be acceptable.

(7) Controllability.

(i) Control harmony should be present. There should be no objectionable cyclic to collective or roll-yaw-pitch cross coupling.

(ii) Control forces following a control system malfunction such as a hydraulic system failure should be low enough to allow completion of the intended flight. It may not be possible to land early during an actual IFR flight.

(iii) There should be no tendencies for pilot induced oscillations; there should be no sustained or uncontrollable oscillations resulting from the efforts of the pilot to control the rotorcraft.

(iv) The control system must have sufficient resolution to permit accurate and precise instrument maneuvers. Some control systems with high breakout forces in conjunction with low control force gradients do not lend themselves to satisfactory instrument flight capability.

(8) Cockpit Arrangement.

(i) The primary flight instrument basic T (or a modified T with VSI above the altimeter) should be located directly in front of the pilot. All annunciation necessary for operation of stability systems should be readily in view. Secondary flight (or navigation) instruments such as radar altimeter and secondary radio course information, DME, etc., should be grouped around the periphery of the T. Next in priority are primary power instruments such as torque and rotor RPM. Powerplant instruments and backup attitude information should be placed in the remaining panel areas. Various research and development efforts and previous certification programs have revealed that it is desirable not to locate the standby attitude indicator immediately adjacent to the basic flight instrument T. The standby attitude indicator must be usable and flyable from the primary pilot station (and any other pilot station); however, locating it too close to the primary instruments may be undesirable and should be evaluated. If the standby attitude information is close to the pilot's normal flight instrument scan, he may begin to compare attitude information between the two indicators in his normal instrument scan. Every pilot eye motion to compare these indicators could be a wasted motion that could be more efficiently applied in the normal scan. The pilot should fly either the primary or the backup indicator and it may be an aid if these indicators are noticeably separated. When the standby indicator is located apart from the normal scan and the primary indicator fails, the pilot is conscious of a distinctly different instrument scan and is less likely to be continuously coming back to the center of the basic T for attitude reference. Physical separation can assist the transition to standby attitude flight.

(ii) All cockpit controls necessary for normal and emergency operations should ideally be located so that they may be actuated without upper body movement. Moderate head and body movement has been accepted; however, these motions must be evaluated for their vertigo inducing effects. No IFR controls should be located aft of a vertical plane passing left to right (laterally) through the pilot's body.

(iii) If a copilot position is approved, the copilot must have a complete set of flight controls, and a complete set of primary flight instruments. The copilot must be capable of independently flying and navigating the rotorcraft from his position. The copilot must be capable of controlling at least one primary navigation source so that he can operate the rotorcraft during normal conditions without relying on the first pilot to perform needed cockpit functions. Some instruments can be shared between pilots depending on instrument panel presentation. Some examples from previous programs include standby attitude, rotor tachometer (if the aircraft has automatic governing and the crew is provided visual and aural RPM warning), and secondary powerplant instruments such as N_G, oil pressure, and temperature.

(iv) Proper cockpit annunciation is essential for safe operation. SAS and autopilot modes must be properly annunciated. Appropriate annunciator color coding is contained in § 29.1322. There must be no question in regard to the source of navigation information presented to the crew. Where navigation switching is available between individual displays and between pilot positions, the first pilot should have overriding control for his displays.

(9) <u>IMC Evaluation</u>.

(i) As part of the flight test program, new rotorcraft undergoing IFR certification should be flown in the air traffic control system in actual day and night instrument meteorological conditions. Items for consideration during the IMC evaluation include:

(A) Ability of the rotorcraft to safely operate in the National Airspace System, including crew capabilities to cope with probable malfunctions. Examples of failures imposed during this IMC evaluation on previous programs are shown below:

(<u>1</u>) Hydraulic failure

(<u>2</u>) Individual COMM, NAV, or intercom failure

(<u>3</u>) Engine failure

(<u>4</u>) Loss of any power input

(<u>5</u>) SAS failure

(<u>6</u>) Trim failure

(<u>7</u>) Individual failure of each vertical and directional gyro

(B) Visibility during low approach conditions in precipitation.

(C) Glare and reflections at night in clouds.

(D) Workload demands on the minimum flight crew including the failures in paragraph (9)(A)(<u>1</u>) above.

(E) Handling qualities in turbulence throughout the IFR approved envelope including typical IFR flight maneuvers,

(<u>1</u>) With reasonably anticipated stability augmentation system failures,

(<u>2</u>) With reasonably probable control system failures (hydraulics, force trim, basic ship systems, etc.),

(3) With the typical workload conditions associated with operating in high density traffic areas, and

(4) With other reasonable, probable failures.

(F) Cockpit leaks in precipitation which affect pilot efficiency, safety, or rotorcraft airworthiness.

(ii) Rotorcraft that are an improved, modified, or later model of previously approved type that have no significant changes in the fuselage and windshield configuration, the aircraft lighting system, and the rain removal systems do not need to be flown in clouds. They may need to be evaluated in clouds if, in the judgment of the flight test personnel, there is some doubt as to the similarity of the configuration. However, a previously approved rotorcraft undergoing IFR certification tests for a different Stability Augmentation System should not require a series of actual IFR flights just to determine pilot workload, or whether it can be flown in clouds.

(10) Static Position Error. The static position error should be reevaluated to determine altimeter error during instrument approach conditions. This is particularly important when high angle approaches (above 3°) are approved. Static position error for 3° approaches can typically be approximated by the level flight error. Level flight error is constrained by the requirements of § 29.1325(f). The direction of error is important. If the indicated value is lower than actual value, the error is in a conservative direction and further investigation may not be required. The direction and magnitude of static position error should be determined for steep angle approach conditions and additional information provided when necessary in the Rotorcraft Flight Manual. An investigation of static system response during the go-around transition should be investigated.

(11) Cross Coupling. IFR handling qualities are enhanced by providing low levels of coupling between axes. During the flight evaluation, pilots should be alert for strong cross coupling tendencies between yaw and pitch, heave (collective) and pitch, heave and roll, or roll and pitch. Any strong coupling effects between these motions may produce unacceptable handling qualities for IFR flight. The rotorcraft must be able to make a smooth transition from any flight condition. As an example, large rolling or pitching moments with collective application would represent questionable handling characteristics for the IFR missed approach condition.

(12) Electrical, Avionics, and Instruments. Some aircraft have been certified with different equipment from that suggested in this subparagraph because the certification criteria for IFR has evolved in several stages. The following guidance refers to the latest certification requirements:

(i) Additional Avionics/Instruments. The avionics/instrument required for IFR certification beyond those required for VFR certification should be as follows:

(A) Standby Attitude Indicator in place of a rate of turn indicator required by § 29.1303(g). Power for operation and lighting must be independent from the rotorcraft electrical generating/starting system. Operation must be maintained for 30 minutes after total aircraft electrical power generating system failure.

(B) Alternate Static Source. An alternate static source with a means of selecting this source must be provided for single pilot configurations.

(C) Thunder Storm Lights. Thunder storm lights are high intensity white lighting that flood the instrument panel area containing the basic flight instruments.

(D) Direction Indication, Gyro Stabilized. Magnetic in place of non-magnetic required by § 29.1303(h).

(E) Navigational Systems. Navigational systems required by the applicable operational rules must be provided.

(F) Communication Systems. Communication systems required by the applicable operational rules must be provided.

(G) Other electrical/electronic equipment. Other electrical/electronic equipment required by the applicable operational rules must be provided.

(ii) Electrical Power Availability for Avionic and Instrument Systems. Minimum avionic and instrument systems should remain operative after electrical power failures in relation to IFR operation. The lists that follow suggest the minimum Avionic and Instrument Systems that should remain operational after a single failure of the generating system and after failure of all but the emergency power source. These lists do not address the basic equipment required for non-IFR related operation. These basic equipment requirements are addressed by the appropriate paragraph of this AC. Where a time-limited power source is provided for compliance with FAR 29.1351(d)(2), in determining the endurance it should be assumed that flight under instrument flight rules will be continued for a period of not less than 30 minutes following the failure of the normal electrical power generating system.

(A) Avionic and instrument systems that should remain operational, for IFR approved rotorcraft, after a single failure of the electrical generating system. The rotorcraft must be capable of IFR flight for one-half the maximum cruise duration. The suggested minimum avionic and instrument systems are as follows:

(1) Flight Instruments. Same as § 29.1303 requirements, except as defined by subparagraphs AC 29 Appendix B (12)(i)(A) and (D).

(2) Communications. One VHF radio.

(3) Navigation System. One navigation system, including necessary sensor inputs such as directional gyros.

(4) Transponder.

(5) ICS System. Required for two pilot approval.

(6) Instrument Lights (or equivalent).

(B) Avionic and instrument systems that should remain operational, for IFR approved rotorcraft, after total failure of the electrical generating system. The rotorcraft must be capable of flight for a minimum of 30 minutes. The suggested minimum equipment is as follows:

(1) Magnetic Compass.

(2) Airspeed-Altitude-Attitude Presentation.

(3) Communications One VHF System.

(4) Instrument Lights (or equivalent).

(5) ICS System-For Two Pilot Approval.

(C) Additional requirements for Category A rotorcraft. Where a time-limited power source is provided for compliance with FAR 29.1351(d)(2), in determining the endurance it should be assumed that flight under instrument flight rules will be continued for a period of not less than 30 minutes following the failure of the normal electrical power generating system.

(iii) Directional Instruments. A magnetic, gyro stabilized direction indicator is specified because navigation in instrument flight must be precise. In rotorcraft, the nonstabilized magnetic indicator is subject to many errors, particularly in turbulence. Therefore, it is inappropriate as the primary source of directional information, but it is adequate as an emergency source. A nonslaved directional gyro is also inappropriate as the primary source of directional information because of drift and the requirement to set it to some other precise reference.

(A) As a minimum for single pilot IFR, a nonstabilized magnetic indicator (such as a “whiskey compass”) and a magnetic gyroscopically stabilized direction indicator system (slaved) are required.

(B) The minimum for dual pilot certification includes the instruments required for single pilot, and an additional independent gyroscopically stabilized directional indicator system (slaved or unslaved).

(13) IFR Electrical System.

(i) General.

(A) The entire electrical system, both AC and DC portions, must be reviewed with IFR operation in mind. This review is necessary since most of the rotorcraft presently certificated do not include IFR operation as part of their certification. Many aspects of normal operation and results of failure conditions may be entirely acceptable for VFR operation, but unacceptable for IFR operation.

(B) Provisions should be made for a capability to continue flight for one-half the maximum cruise duration in the event of a single failure in the electrical system. Paragraph AC 29.1351 contains the definition of a “single failure.” The evaluation of the system under failure conditions should consider not only the failure itself, but also the recommended cockpit procedure to respond to any failure.

(C) The fault analyses of the electrical system and the results of the system testing to validate that analysis serves as a good starting place for the electrical system review. Failure of each generator, each battery, and each component, such as switches and relays, should be accounted for first since failure of equipment and components are the most probable.

(D) System failure such as tripped circuit breakers, blown fuses, loss of busses, loss of feeders, loss of ground terminals, and failure of electrical disconnect plugs should also be considered.

(E) Routing of all wiring from each power source throughout the distribution system should be reviewed. In all instances feeder wires should be routed separately from small gage control wiring. Also, wiring for each power system should be separated to the maximum extent practical from the wiring associated with other required power systems.

(F) A single electrical disconnect plug should not contain wiring for more than one generating system. Many systems incorporate automatic feeder fault protection that disables a power source experiencing a short circuit on its feeder, and in some instances passive protection has been provided for the feeders.

(G) There may be other failures that should be considered that are peculiar to the specific design being evaluated, and if so, an appropriate accounting of these failures should also be made.

(ii) Review of Regulations. The airworthiness regulations concerning electrical systems begin with § 29.1301 (reference Subpart F - Equipment) and continue up to § 29.1411. Other rules may also concern the electrical system; however, compliance with these sections should have been assured as part of the original VFR approval.

(iii) Specific Emphasis Areas. In some previous installations, changes have been necessary in the areas listed below. Future installations should be checked carefully in these areas and other areas that indicate a need for attention.

(A) Systems Affected by Icing. Gross inaccuracies in altitude and airspeed indicators resulting from icing could be disastrous in IFR flight. For rotorcraft not equipped with approved alternate static sources, static ports should be carefully evaluated and should either be heated or an analysis verified by flight test data submitted to substantiate leaving them unheated. Static line routing should be carefully evaluated for low spots. Also, if static ports are on the side of the rotorcraft, the lines should be initially routed upward just behind the static ports, then down to a drain. If the lines are initially routed upward, the lines will not fill with water when the rotorcraft is flown through rain or is washed.

(B) Overvoltage Protection. If the rotorcraft is certificated under Part 29, Category A, it is required to have overvoltage protection. Other rotorcraft may have this protection, but many do not. Since overvoltage protection is specifically required for IFR operation, the rotorcraft's basic electrical system should be very carefully reviewed for this capability.

(C) Power Adequacy Indication. Most flight instruments that use a power supply have a visual means integral with the instrument to indicate the adequacy of the power being supplied. For those required flight instruments that are not provided with a visual means, the following must be accounted for:

(1) The visual means provided must be at least adjacent to the instrument.

(2) The visual means must be adequately placarded.

(3) The power must be measured at or near the point where it enters the instrument.

(4) For electrical instruments, the power is considered to be adequate when the voltage is within approved limits. The source of power for the visual means of indication must be independent of the source of power for the instrument itself. Independent in this case means a separate circuit protective device and a separate distribution system bus.

(D) Multiple System Separation. Multiple systems performing the same function are required in certain instances because it is probable that a single system will fail. Separation of such systems would preclude a single fault from causing a multiple system failure. The following should be considered:

(1) When possible, cable routing should be accomplished to assure the maximum separation; for example, one system routed on one side of the rotorcraft and the other system on the opposite side. Some areas, such as pedestals, junction boxes, and equipment racks bring systems close together, and in these areas physical separation may be minimal.

(2) Systems that are required to be duplicated should not be routed through one electrical disconnect plug.

(3) System grounds should be evaluated to assure wiring for two required systems are not grounded to the same terminal. If a terminal strip contains grounds for multiple systems, it should be grounded to the rotorcraft's airframe in two places from two separate terminals.

(E) Circuit Protective Devices. All systems that are "required" for IFR operation are considered to be necessary for safe IFR operation, and the circuit protective devices for those systems should generally be accessible to the crew in the cockpit so they can be readily reset or replaced in flight. For example, where a capability is provided that is above the minimum certification requirements, accessibility may not be an issue. A tradeoff here, however, is that additional equipment may be required for dispatch in IFR operation.

The location of the generator field protective devices has been a problem in some rotorcraft. The protective devices that can result in the loss of a required power system source should be capable of being reset or replaced in the cockpit while in flight. This position is further supported by the occurrence of nuisance opening of circuit protective devices in rotorcraft. Further discussion on this issue is included in paragraph AC 29.1357b(4).

(F) Intercommunication System. All audio for the entire rotorcraft comes together at this system. An evaluation should be made to assure that no single failure will result in the loss of all audio for the rotorcraft. Check for common grounds, common connectors, etc. Power inputs should also be disabled.

(14) Rotorcraft Flight Manual Material.

(i) In addition to other required information, the limitations section of the Rotorcraft Flight Manual (RFM) or RFM Supplement must include the approved IFR flight envelope, minimum IFR crew requirements, the minimum required equipment for dispatch into IFR conditions that is not covered by the operating regulations, and the maximum approach gradient which has been approved. If a significant loss of altitude is experienced in any flight regime or maneuver during certification analysis or testing, the emergency operating procedures should include a statement of this altitude loss along with any other appropriate information.

(ii) The limitations section of the RFM should not include restrictions prohibiting external cargo operations. These operations are covered by FAR Parts 91 and 133 and all external load operations conducted under these parts must be approved by the controlling operations inspector. It is the responsibility of the operator to demonstrate and the operations inspector to confirm that any external load operation, including en route IFR, can be safely conducted.

(15) Rotorcraft Flight Below Instrument Flight Minimum Speed.

(i) The advent of steep angle, decelerating precision instrument approach procedures will necessitate flying at airspeeds below the instrument flight minimum speed (V_{MINI}) established for most rotorcraft under FAR 29, Appendix B, Paragraph 22(c).

(ii) Applications for findings of equivalent safety to approve instrument flight below V_{MINI} will be considered for rotorcraft meeting at least the following criteria:

(A) The rotorcraft is certified for IFR flight.

(B) For constant airspeed approach approval: a minimum approach airspeed is specified by the applicant, at which the rotorcraft is demonstrated to be safely controllable and capable of instrument flight without undue pilot effort for the duration of the approach and transition to missed approach, including acceleration to an airspeed above V_{MINI}.

(C) For decelerating approach approval: a two or three cue flight director is provided as required equipment, and the rotorcraft is demonstrated to be safely controllable and capable of instrument flight without undue pilot effort for the duration of the approach and transition to missed approach, including acceleration to an airspeed above V_{MINI}.

(D) The rotorcraft is demonstrated to be safely controllable following single failures of aircraft systems not shown to be extremely improbable at the minimum approach airspeed specified by the applicant or encountered during a decelerating approach.

(E) The RFMS contains the following information in addition to the requirements of Paragraph IX of Appendix B to FAR 29:

(1) Minimum approach airspeed, if applicable.

(2) Additional aircraft equipment requirements for flight below V_{MINI} and/or the minimum approach airspeed, if applicable.

(3) Maximum approach angle.

(4) Maximum allowable surface wind for safe conduct of the approach.

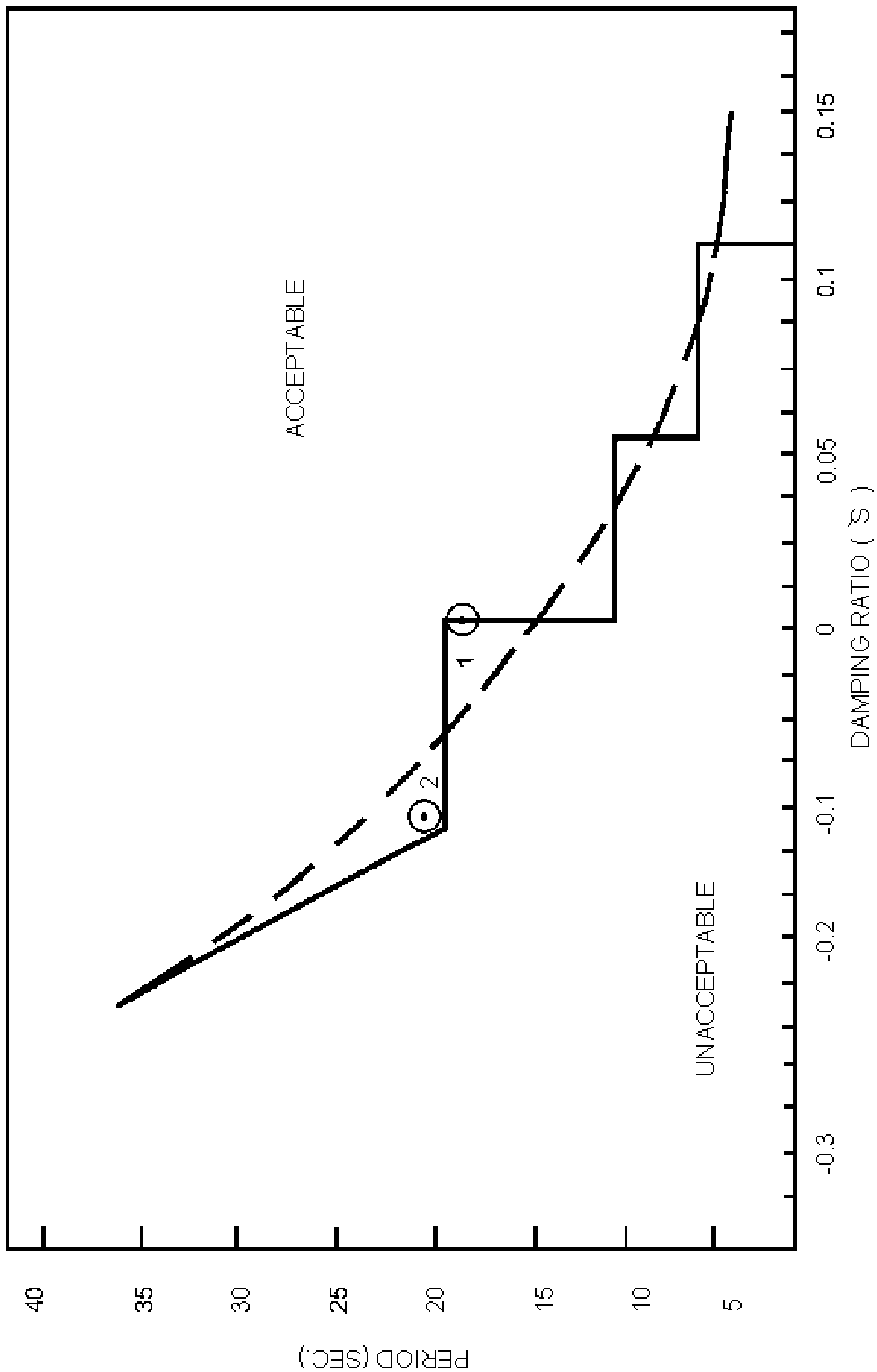

FIGURE AC 29.APX B-1 ROTORCRAFT DYNAMIC STABILITY REQUIREMENTS FOR IFR